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EFFECTS OF HERBICIDES ON THE SOIL FAUNA

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Summary Herbicides may affect populations of soil invertebrates either directly or indirectly when the chemical affects the vegetation on which many of these animals feed. The direct effects of only DNOC, MCPA, 2,4-D, 2,4,5-T, TCA, dalapon, monuron, linuron, tri-allate, simazine, atrazine and paraquat have been studied to date and the only herbicides that had effects on numbers of soil invertebrates were DNOC, TCA, monuron, simazine and Shell WL 19805. The direct effect of herbicides were never severe and with TCA and monuron they occurred only after very large doses were applied to the soil. Three recent experiments with simazine, Shell WL 19805 and paraquat are described. Simazine and Shell WL 19805 slightly decreased numbers of enchytraeid worms, predatory mites and isotomid Collembola and Shell WL 19805 increased numbers and weight of earthworms. Paraquat had little effect on invertebrate populations. It seems that the only herbicides likely to influence numbers of soil invertebrates directly are DNOC and the triazines. None of these effects would adversely affect soil fertility.

INTRODUCTION

Many herbicides are selected because they destroy plants by interfering with specific metabolic processes in plants. Consequently, they are rarely very toxic to animals and it might be expected that their direct influence on populations of soil invertebrates would be slight. Nevertheless, herbicides might greatly influence numbers of invertebrates by affecting the surface flora, because many of these small animals feed on plant roots or decaying plant material, and some may be specifically associated with a few species or genera of plants. Thus, herbicides, by making the species of plants fewer, may indirectly diminish the number of species of invertebrates in the soil without necessarily making the total numbers of animals smaller. There have been few studies of the influence of herbicides; this is not surprising because until recently there have been few studies even of the effects of insecticides on soil animals (Edwards, 1965, 1969). Those that have been made, differ greatly in approach, ranging from studies of the effects of applying herbicides directly to soil, to tests with plants in pots or full scale field experiments; often the indirect effects have not been distinguished from the direct ones (Table 1).

DNOC has consistently decreased the numbers of mites and springtails (van der Drift, 1963; Karg, 1964; Edwards, 1964; Bieringer, 1968) and also insects and larvae (van der Drift, 1963; Johnson et al, 1955). None of the workers who investigated MCPA, 2,4,5-T or 2,4-D-sodium found any direct influence on the soil fauna. TCA seemed to influence numbers of soil animals slightly because Fox (1964) reported increased numbers of millipedes, springtails and mites after treatment, and decreased numbers of earthworms; but these were probably indirect effects. Wojewodin (1958) reported that a large dose of TCA (100 kg/ha) greatly decreased numbers of wireworms, earthworms, millipedes and springtails although not those of mites, but such doses would not be used in practice.

The only reports that dalapon affected the soil fauna were by Fox (1964) and Curry (1970) and these were indirect effects. Fox (1964) also reported some

Table 1

Investigations into the effects of herbicides on the soil fauna

Author / Herbicide	Von Baudissin, 1952	Wojewodin, 1958	Steinbrenner, 1960	Ilin, 1961	van der Drift, 1963	Rapoport, 1963	Karg, 1964	Edwards, 1964, 1965, 1969	Fox, 1964	Davis, 1965	Bieringer, 1968	Wicke, 1968	Curry, 1970	Johnson et al., 1959
MCPA						O		O		O	O			
2,4,5-T					O									
2,4-D	O			O		O			O		O			
TCA		-*							±					
dalapon					O	O		O	+				-	
paraquat								O					-	
monuron		-*							-					
linuron								O						
tri-allate								O						
atrazine									-					
simazine		-*	O	O				-				-		
Shell WL 19805								±						
DNOC					-		-	-			-			-

O = Herbicide had no effect
\- = Some invertebrates decreased in numbers
\+ = Some invertebrates increased in numbers
* = Effect occurred only at large doses.

decreases in numbers of invertebrates caused by monuron, which he attributed to changes in flora; although Wojewodin found that monuron, at 20 kg/ha decreased the numbers of millipedes and springtails, this is a very large dose. Linuron and tri-allate seemed not to affect soil fauna. Curry (1970) reported smaller numbers of invertebrates in dalapon- and paraquat-treated plots, but these were almost certainly because the vegetation was killed.

Several of the tri-azine herbicides seem to affect soil invertebrates. Fox (1964) reported that atrazine decreased numbers of wireworms, earthworms and springtails. Nematodes were decreased in numbers by simazine (Wicke, 1968) and wireworm, earthworm, millipede and mite populations were much smaller in plots treated with a large dose (20 kg/ha) of simazine (Wojewodin, 1958). Thus, DNOC and the triazine herbicides seem the most likely to affect the soil fauna directly; the influence of DNOC is now well-established and the experiments reported here are concerned mainly with triazines.

METHODS AND MATERIALS

Direct effects of a herbicide - simazine. The first experiment, already summarized (Edwards & Arnold, 1964) was concerned with the toxic effects of four representative herbicides on soil invertebrates. They were MCPA, representing a phenoxyacetic acid type; tri-allate, a volatile persistent carbamate; linuron, a substituted urea; and simazine, a tri-azine. The experiment was designed and organized by Mr. J. D. Fryer, Director of the Weed Research Organization, Kidlington, nr. Oxford. Plots 16 x 30 ft (4.8 x 9.0 m) were laid out in a strip with two replicates of each of the four herbicide treatments and two controls. Doses of 1.5 lb/acre (1.68 kg/ha) of tri-allate, MCPA and simazine, and 0.75 lb/acre (.84 kg/ha) of linuron, were applied twice annually from 1963 onwards. All treated and untreated plots received identical cultural treatments designed to prevent any appreciable growth of plants, thus obviating any indirect effect of the herbicides.

One week after the second treatment and at monthly intervals thereafter, eight 2 in. (5 cm) diameter and 6 in. (15 cm) deep soil cores were taken at random from each plot, and the animals extracted from these in a modified high gradient Tullgren funnel (Edwards & Fletcher, 1969).

Only simazine, influenced numbers of soil invertebrates; even this affected only enchytraeid worms, onychiurid and isotomid Collembola and predatory mites. Figs. 1-4 summarize the population changes of these animals after simazine treatments. A similar set of samples (Table 2) was also taken on 26 June 1969, approximately six years after the experiment was begun.

Table 2

Samples taken from the simazine experiment on 26 June 1964

Animal group		Mean number of animals/5 cm soil core					
		simazine			control		
		Rep. I	Rep. II	Mean	Rep. I	Rep. II	Mean
Acarina	Prostigmata	2.7	4.0	3.4	6.0	9.5	7.7
	Mesostigmata	0.2	0.2	0.2	1.7	2.9	2.3
Collembola	Onychiuridae	2.3	1.2	1.8	3.1	0.5	1.8
	Isotomidae	0	0	0	0.5	1.9	1.2

Direct and indirect effects of a herbicide - Shell WL 19805. The herbicide Shell WL 19805 is very closely related to simazine. The numbers of soil invertebrates in untreated plots 4 m^2 were compared with those in plots treated with 4 kg/ha of Shell WL 19805. There were four untreated plots, four that were rotovated after being sprayed and four with the herbicide left on the soil surface. No attempt was made to keep the plots free from vegetation. Four soil cores 2 in. (5 cm) diameter by 6 in. (15 cm) deep, were taken from each plot, two weeks after spraying and thereafter at approximately monthly intervals, and the invertebrates extracted in modified high-gradient Tullgren funnels. Figs. 5 and 6 show the populations of invertebrates in the treated and untreated plots.

Direct and indirect effects of a herbicide - paraquat - and cultivation. In a long-term investigation of the effects of paraquat and cultivation on soil invertebrate populations, plots 0.03 acre (.012 ha) were either ploughed or treated annually with paraquat at 8 pints a.i./acre (11.4 l a.i./ha), then slit-seeded with wheat. Soil cores, 2 in. (5 cm) diameter and 6 in. (15 cm) deep, have been taken twice

annually to determine the effects on soil invertebrates, and the earthworm populations studied by sampling 0.5 in.^{2} (3.23 cm^2) quadrats by the formalin method (Raw, 1959) annually during the autumn. The effects of the treatments on the smaller invertebrates varied and differed between seasons but those on earthworms were distinct, with many more in the paraquat-treated unploughed plots than in the ploughed and cultivated ones (see Table 3).

Table 3

A comparison of earthworms in ploughed plots and paraquat-treated slit-seeded plots

Year	No. of earthworms (per m^2) paraquat	No. of earthworms (per m^2) ploughed	Wt. of earthworms (gm/m^2) paraquat	Wt. of earthworms (gm/m^2) ploughed
1967	431	25	70.9	2.0
1968	431	331	108.5	43.7
1969	344	487	36.0	25.2

DISCUSSION

Keeping the treated and control plots free from vegetation in the first experiment, excluded any indirect effects of the herbicide on the soil fauna, and measured only the direct effect of the herbicide on the fauna. The direct effects of simazine were small and probably unimportant, although the repeated treatments kept populations of some small invertebrates continuously below those in untreated soil. Predatory mites and isotomid Collembola were the most susceptible animals to simazine and these small animals are much more sensitive than other soil invertebrates to many pesticides, probably because they are more active and pick up more of the chemical as they move through the soil.

In the second experiment, the weeds were not removed and although the herbicide-treated plots carried only sparse vegetation there was a relatively dense cover of weeds and grass on the control plots. This almost certainly caused the smaller numbers of certain invertebrates in the treated plots. Once again the only groups affected by the herbicide were the enchytraeid worms, predatory mites, isotomid Collembola and an additional group, the oribatid mites. Clearly, leaving the herbicide on the surface had a greater effect on soil invertebrates than rotovating it in, but it is not clear whether this was a direct or indirect effect. The earthworms were significantly more numerous in the herbicide-treated plots (Fig.9); this must have been an indirect effect, and as there was less vegetation on these plots, it was probably because there was more dead plant material on the surface of the soil.

The paraquat experiment introduced a second indirect factor, that affected numbers of soil invertebrates, namely cultivation. Nevertheless, no long-term effects of the herbicide treatment on the smaller soil invertebrates was apparent. During the first years of the experiment, there were many more earthworms in the paraquat-treated plots than in the ploughed ones (Table 3), but in 1969 there were actually more in the ploughed ones. This could reflect any one of several indirect factors. There is no evidence from this experiment that paraquat has any directly deleterious effect on the soil fauna. These three experiments demonstrate the need for different methods to assess the overall effects of a

herbicide treatment on soil invertebrates, and to consider both direct and indirect effects of the herbicide and of any associated cultivations.

To summarize the results from these experiments, and those of other workers, the only herbicides with any direct influence on the soil fauna are DNOC and some of the tri-azines, and the effects of these are slight and unlikely to affect soil fertility. However, there is still need for vigilance concerning such direct effects, when chemicals are screened as herbicides, and for further careful investigation on the effects of existing herbicides on the soil fauna.

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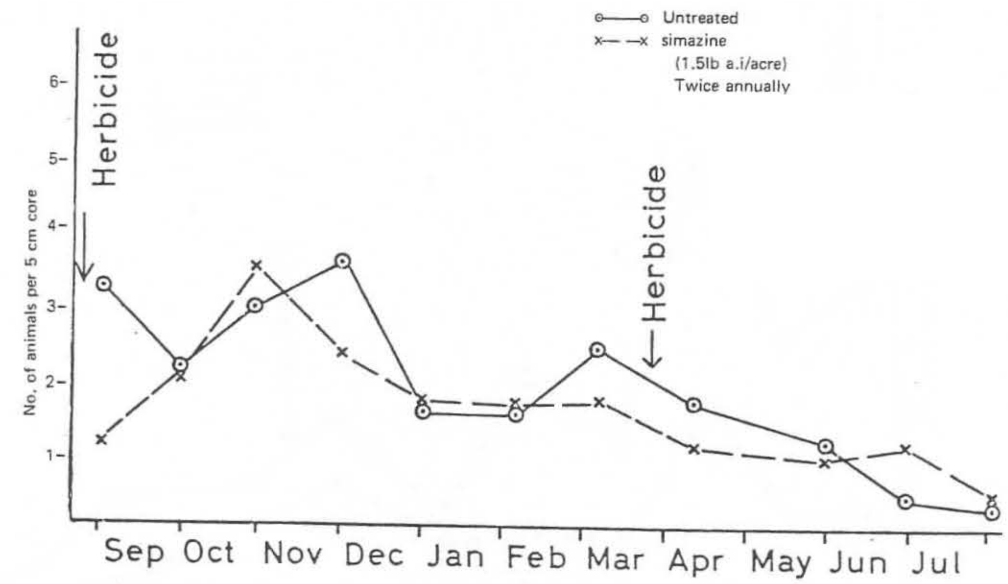

Fig.1 Effects of simazine on enchytraeids

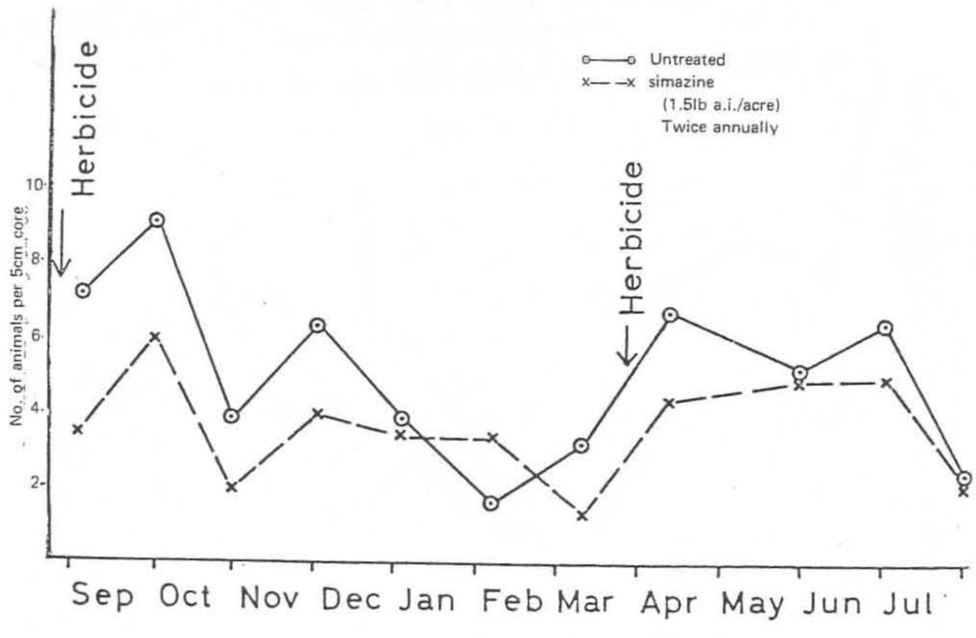

Fig. 2 Effects of simazine on onychiurid Collembola

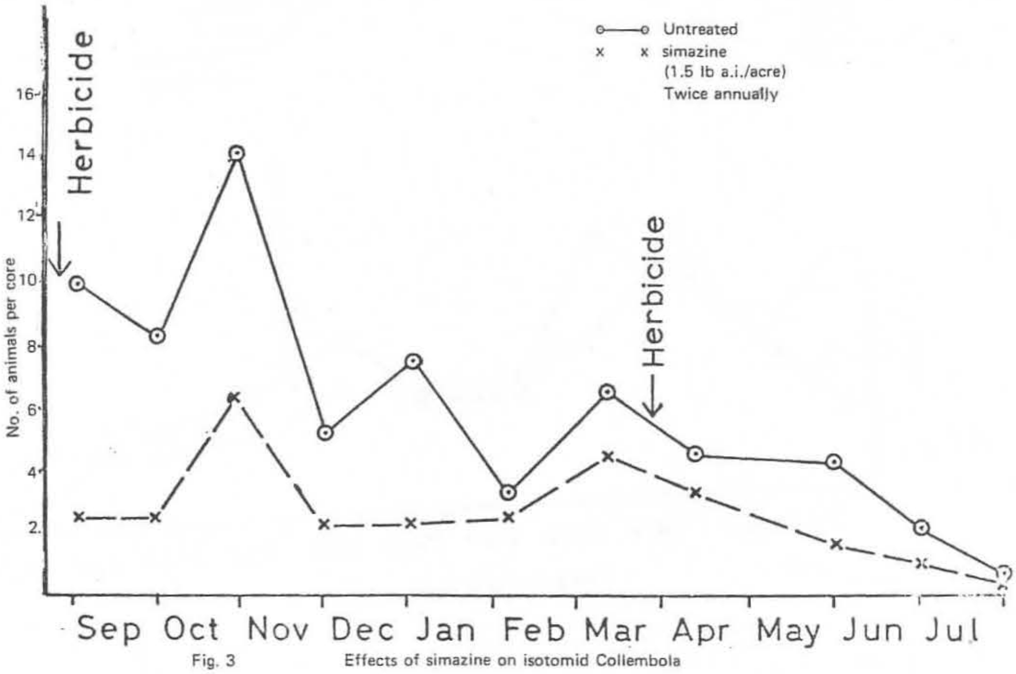

Fig. 3 Effects of simazine on isotomid Collembola

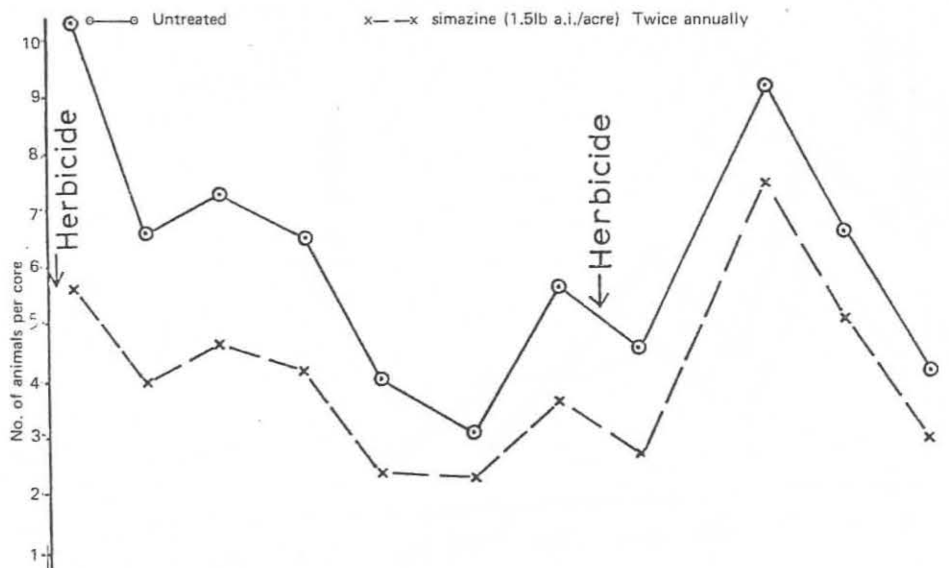

Fig. 4 Effects of simazine on predatory mites

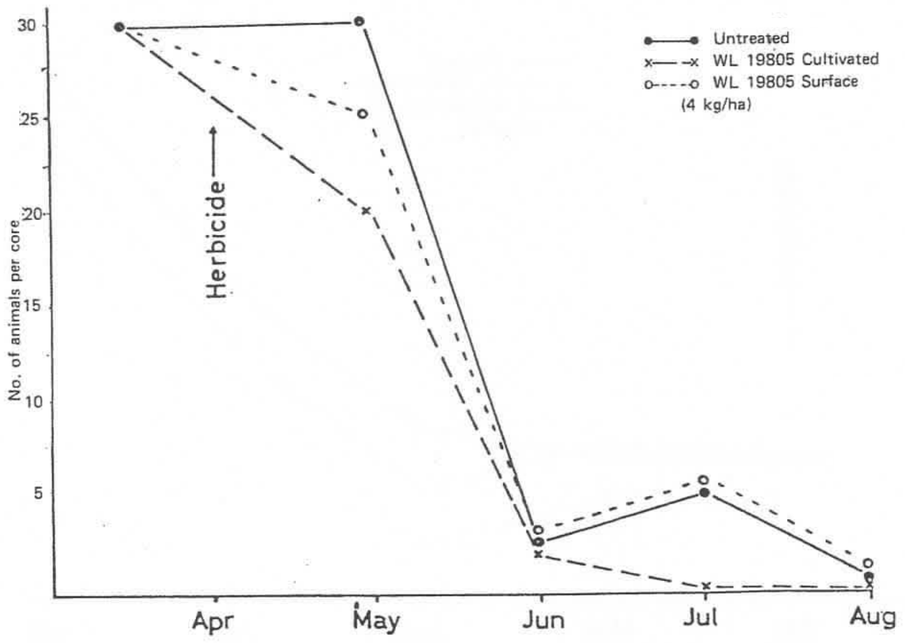

Fig. 5 Effects of Shell WL 19805 on enchytraeids

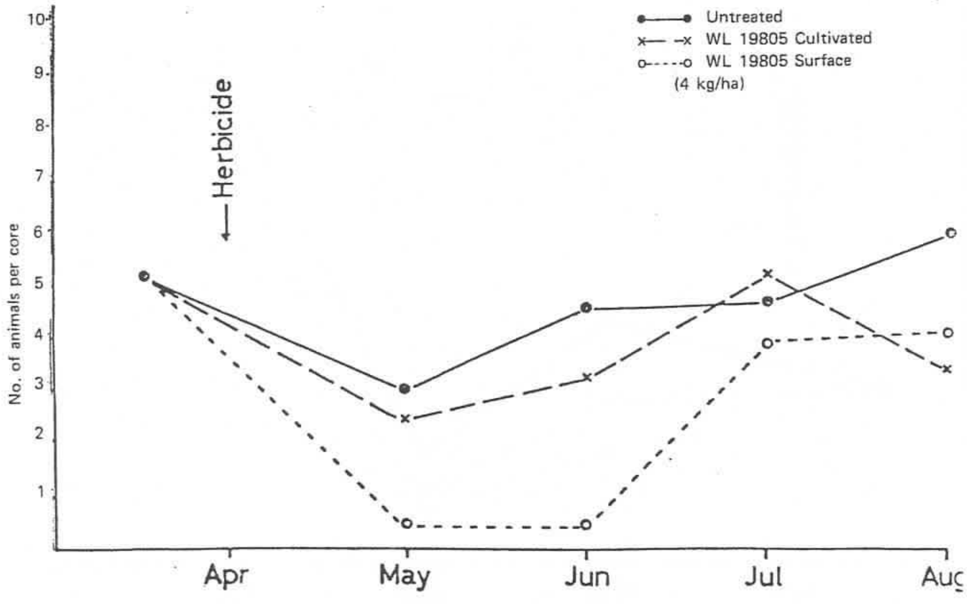

Fig. 6 Effects of Shell Wl 19805 on isotomid Collembola

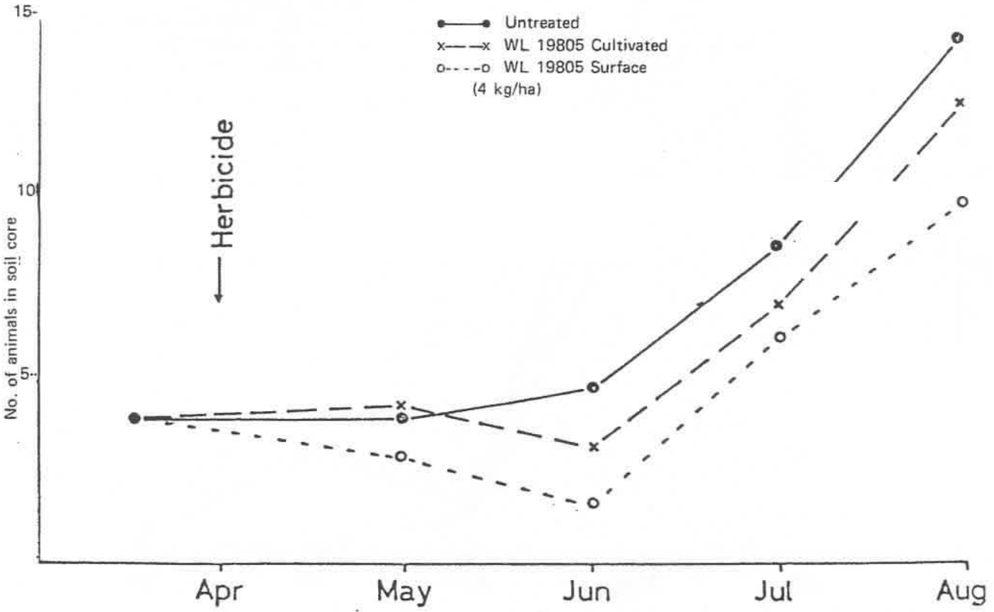

Fig. 7 Effects of Shell WL 19805 on predatory mites

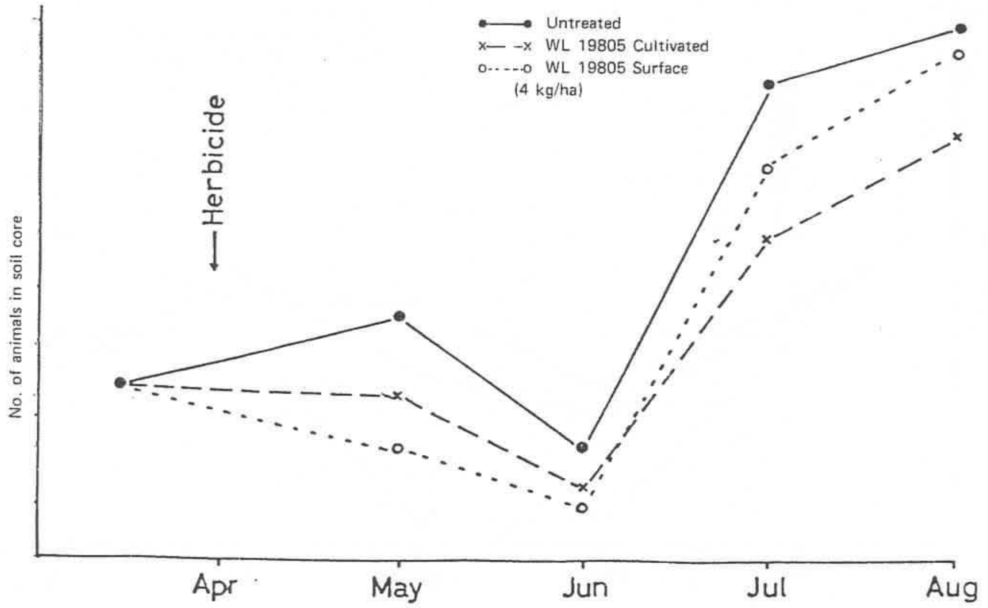

Fig. 8 Effects of Shell WL 19805 on oribatid mites

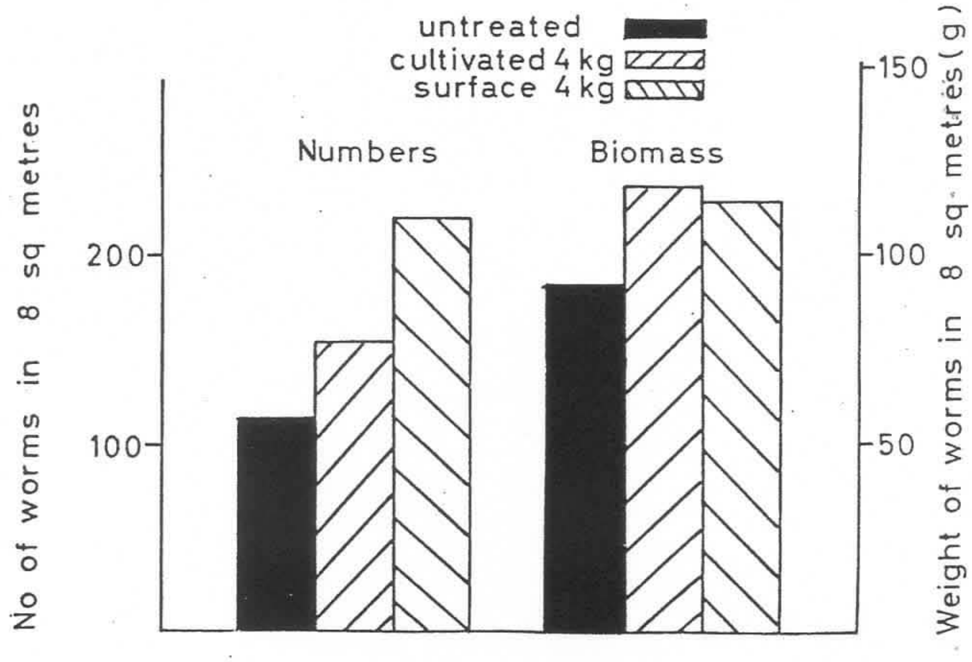

Fig. 9 Effects of Shell WL 19805 on earthworms